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Wire Rope Sling Failure Analysis: Technical Root Causes, Investigation Methodology Critique, and Lessons for Lifting Safety and Organizational Learning

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Abstract: Wire rope slings are critical in heavy lifting operations, yet their failure remains a persistent safety concern. This paper presents a case study of a catastrophic sling rupture that occurred during a heavy lifting trial, despite the lift being within its rated capacity. A multi-faceted failure analysis identified hidden corrosion fatigue at the sling's ferrule and an unanticipated extreme overload condition as the primary technical root causes. Procedural and organizational factors—including inadequate risk assessment, deviation from critical lift protocols, and failure to act on prior lessons—also contributed to the incident. The contractor's investigation is critically reviewed against best-practice Root Cause Analysis guidelines, highlighting both strengths and gaps in its methodology. Key lessons to improve lifting safety are discussed, such as implementing rigorous inspection and retirement criteria for aging slings and ensuring comprehensive lift planning. Overall, the case underscores the importance of robust investigation practices and effective organizational learning to prevent similar failures in the future.

Keywords: Wire Rope; Lifting Slings; Corrosion Fatigue; Failure Analysis; Root Cause Analysis; Failure Investigation; Lifting Operations; Safety Culture; Organizational Learning; Accident Prevention

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1. Introduction

Wire rope sling failures remain a persistent problem in heavy lifting operations, even when standard industry procedures and safety factors are applied. Such failures can have severe consequences for safety and operations [4]. In practice, steel wire ropes inevitably degrade over time through mechanisms like fatigue, wear, and corrosion, requiring diligent inspection and timely replacement to prevent accidents [1]. Nonetheless, recent case studies and incident reports show that sling failures continue to occur in cranes, hoists, and other heavy lift systems, indicating potential gaps in current maintenance and usage practices. Researchers have noted that human and organizational factors (e.g. operational errors or inadequate training) often contribute to these incidents alongside technical causes [4], compounding the challenge of prevention.

Engineering failure analysis of wire ropes have identified a range of mechanical failure modes behind sling accidents. Fatigue cracking is one of the most frequently reported causes; for example, a broken crane rope was examined and concluded that undetected fatigue cracks (associated with decarburization of the steel) grew over time due to poor inspection practices [7]. Corrosion is another critical factor: corrosion pitting and rust can significantly weaken rope wires and shorten their service life, making fatigue failures more likely [8]. Wear and abrasion (both external and internal) also contribute to degradation – a cableway rope failure was initiated by excessive pressure on the rope, which caused slipping between inner and outer wire layers and led to strand breakage [3]. Likewise, overloading or abnormal loading conditions can precipitate sudden failure; Lateral pressure on a rope (e.g. sharp bending or crushing forces) drastically reduced its load-bearing capacity in a ropeway accident, resulting in fracture [6]. Often, multiple degradation mechanisms act in combination. Steel wire ropes are typically subject to several simultaneous damage processes (fatigue, corrosion, wear, etc.), which can lead to premature and unexpected rope breakage if not detected [5]. Indeed, field experience has recorded wire rope sling failures occurring well before the expected service life – for instance, slings designed for decades of use have sometimes failed in just a few years of operation [9]. These observations underscore the need to pinpoint why such failures occur despite following standard guidelines.

Given the diverse causes and the potential complexity of sling failures, a rigorous failure investigation is essential after any such incident. Best practices from the literature suggest that investigations should be comprehensive – integrating on-site field assessments, detailed fractographic and metallurgical examination of broken wires, mechanical testing, and stress analysis – to accurately determine root causes [4]. In practice, many scholarly case studies demonstrate the value of this approach. For example, a 12-ton overhead crane rope that snapped after only 53 days in service; through careful visual inspection, stereoscopic microscopy, SEM fractography, and hardness tests, it was discovered that localized plastic deformation and wear on individual wires had created stress concentrations that eventually led to a fatigue failure of the rope [2]. Similarly, corrosion effects must be factored into any root cause analysis – the fatigue tests on high-strength wires revealed that corrosion markedly steepens fatigue S–N curves and lowers the wire's endurance, indicating a much shorter life in corrosive environments [8]. Advances in analytical modelling are also aiding investigations: it was developed a share-splitting slip theoretical model for wire rope sling fatigue and validated it with experimental data and electron microscopy of fracture surfaces [9]. All of these studies highlight that only a systematic and critical investigative methodology can unravel the often multi-faceted reasons behind sling failures.

This paper focuses on a recent real-world incident in which a wire rope sling catastrophically failed during a heavy lifting trial. In the incident, a large module panel was being lifted and manoeuvred by a crane (via a pair of wire rope slings and shackles) when one of the slings suddenly parted under tension. Notably, the lift plan had followed standard procedures – the hardware was within its rated Working Load Limit (WLL) and an exclusion zone was enforced – yet the sling still failed unexpectedly. A contractor-led investigation was carried out to determine the cause of this sling failure. The objective of this paper is to critically review that investigation, using the incident's findings as a case study for analysis. The sling failure investigation and its conclusions will be examined in light of the best practices, standards, and investigative methodologies outlined in the literature. In particular, comparing the contractor's process and outcomes with those recommended by prior failure analyses (e.g.

thorough root cause analysis, consideration of all potential failure mechanisms, and technical forensic techniques as noted above). Through this review, this paper aims to identify any gaps or deviations in the investigative approach and to discuss how these may have influenced the understanding of the failure.

In summary, this Introduction has outlined the recurring issue of wire rope sling failures and the critical need for meticulous investigations when such failures occur. The following sections of the paper will present the details of the incident and the contractor's investigation findings, then provide a discussion comparing those findings with established knowledge. Ultimately, the goal is to extract key lessons learned from the case and to propose practical improvements for future incident investigations in heavy lifting operations, so that similar failures can be better prevented or appropriately analysed in the future.

2. Methodology

This study uses a qualitative case-study methodology to assess the investigation process of the wire rope sling failure. Observational data from the incident, including the steps taken during the investigation, were reviewed in detail. The analysis compares the contractor's methods and conclusions with established failure analysis practices, specifically examining whether the root causes were fully identified in alignment with findings from similar peer-reviewed case studies.

2.1 Data Collection and Review Approach

All available data from the contractor's investigation was first collected during presentation and information distribution through email correspondence, meeting and then examined. Key factual information was extracted, including the sequence of events leading up to the sling failure, the condition of the failed sling and associated hardware, and any analysis or tests the contractor performed (e.g. visual examinations, measurements, etc.). This information provided a baseline understanding of what the contractor did during their failure analysis. No additional experiments or field inspections were conducted in this review; instead, the contractor's own evidence (photos, fracture observations, load estimates, etc.) was used as the primary data set. Data from field (photos) and investigation (through interview to personnel whom involved) information sharing as source material to be evaluated rather than as formal results to be accepted at face value.

This case compiles various literatures from both academic journals and industrial standards. By reviewing these sources, it was compiled a set of expectations for a thorough sling failure investigation – for example, checking for signs of metal fatigue, corrosion, wear, overloading, material defects, and reviewing maintenance and inspection records. The literature review also highlighted typical root causes and contributing factors in sling failures that investigators have found in past cases (such as improper use, manufacturing flaws, or inadequate inspection regimes). This set of best practices from prior studies formed the criteria against which the contractor's investigation was evaluated.

2.2 Analytical Framework: Root Cause Analysis (RCA)

The evaluation centered on the principles of Root Cause Analysis (RCA). RCA is a systematic method used to drill down to the underlying causes of a failure by asking iterative "why" questions and examining evidence at each step. Rather than stopping at the obvious immediate cause of the sling failure (e.g. the sling breaking under load), RCA seeks to uncover deeper factors that allowed the failure to occur – for instance, *why* the sling failed at that load, *what* factors (material, design, usage, or organizational) contributed, and *how* similar failures could be prevented. In applying an RCA lens, we reviewed the contractor's investigation to see whether it had identified not just *how* the sling failed, but *why*. This meant checking if the contractor explored multiple facets of causation: the condition of the sling itself (e.g. any pre-existing damage or manufacturing defect), the loading scenario and rigging method, and organizational factors like procedures or training. They were looked for evidence that the failure sequence from the initial event back to potential root causes. For example, did they examine the fracture surface of the sling for tell-tale features of fatigue or overload? Did they consider whether the sling was suited for the load and configuration? Did they review if maintenance or inspection practices missed any warning signs? By systematically answering these questions, we gauged the depth of the contractor's root cause analysis.

It should be noted that various frameworks exist to analyse accidents and failures. One such technique is the Bowtie method, which graphically maps out the pathways from causes to the incident and identifies preventive and mitigating barriers. In the context of this study, the Bowtie approach is mentioned for awareness but was not employed in detail. The Bowtie diagram can be a useful visualization to ensure all potential causes and controls are considered; however, this paper prioritized the RCA approach as it directly focuses on cause-and-effect relationships and is well-suited for pinpointing technical failure origins. Thus, while the contractor's investigation might be visualized in a Bowtie format to check completeness, This paper review did not construct a full Bowtie diagram. Instead, it remained focused on qualitatively evaluating root causes as derived from the investigation.

2.3 Comparison with Published Failure Investigations

Using the information gathered from both the contractor's data input and the literature, we performed a comparative analysis. In practice, this meant evaluating each major aspect of the contractor's investigation against how expert investigations are described in case studies. For instance, if the contractor performed a physical examination of the broken sling, we compared the thoroughness of that examination to those in the literature: Did it include high-magnification fracture analysis or just a naked-eye inspection [2]? If the contractor concluded a certain cause, it need to be checked whether that cause aligns with known failure modes reported by other sling failure analysis. It was also noted whether the contractor identified any contributing factors beyond the immediate cause. Good investigations typically consider human and organizational factors; for example, it was discovered failure found that fatigue cracks had initiated at decarburized (weakened) spots on the wire, and that poor inspection practices allowed the deterioration to go unnoticed until failure [7]. This illustrates how a technical cause (metal fatigue from a material anomaly) and an organizational cause (inadequate inspection) can both be root causes of a failure. In another published sling failure investigation, discovered a manufacturing quality issue: a hoisting rope was inadvertently made with mixed-strength wires, leading to uneven stress distribution and early wire fractures [10]. That case underscored the importance of verifying material compliance and quality control as part of determining why the rope failed.

By drawing on these examples from *Engineering Failure Analysis*, the methodology checks whether the contractor's investigation considered a similarly broad range of factors. Specifically, we assessed if the contractor inspected the failed sling for evidence of fatigue, wear, corrosion, or material defects in the manner experts recommend. We verified if they analysed the sling's load history and usage conditions to identify any misuse or overloading. We also examined whether the investigation reflected on procedural aspects (such as whether the sling was appropriate for the task and if proper pre-use inspections were done). Each of these elements from the contractor's work was compared to the best practices noted in the literature review. Where the contractor's report was silent on an aspect that literature deems important (for example, if no metallurgical analysis was mentioned, despite such analysis yielding critical insights in published case studies), it was flagged this as a potential gap in the investigation. Conversely, if the contractor's approach mirrored what published investigators have done – say, collecting broken sling samples and sending them for laboratory analysis – this was noted as a strength indicating alignment with established methods.

Throughout this review process, the guiding question was: Does the contractor's investigation adequately identify the root cause(s) of the sling failure, and is it as thorough as investigations documented in peer-reviewed case studies? By applying an RCA framework and benchmarking against published sling failure analysis, it needs to ensure that this evaluation is both systematic and grounded in proven engineering failure investigation techniques. This methodology allows the study to objectively support its overall aim, which is to gauge the quality and completeness of the contractor's sling failure investigation in light of known best practices and lessons learned from similar failure cases.

3. Case Description

3.1 Incident Overview and Background

A contractor-led investigation was conducted into the failure of a wire rope sling during a trial lifting operation. The incident occurred during a system integration test (SIT) of a subsea equipment foundation's hinged protection panel. This large steel panel (weighing approximately 19.3 metric tons) is attached to the foundation structure by hinges and is designed to open and close with a relatively small force applied via a single padeye (rated for an 8 metric ton working load). The SIT plan on the day of the incident was to verify the panel's operation by lifting it from horizontal (open) to vertical (closed) using a mobile crane. Prior to the lift, a safety exclusion zone was established around the panel, and all non-essential personnel were cleared from the area. A toolbox talk was held with the lifting team on the morning of the trial, emphasizing that the crane operator should stop the lift if the load exceeded 20 MT (as a precautionary limit given uncertainties in required force).

Equipment and Rigging Setup: The lifting was performed with a heavy crawler crane and a rigging arrangement of wire rope slings and shackles. The crane used was a 350 MT capacity lattice-boom crawler crane, positioned on firm ground at one side of the panel's hinge axis. The panel's dedicated padeye (8 MT WLL) was connected to the crane hook by a series of slings and shackles. Initially, a single 2.5″ wire rope sling was used to attach the crane to the panel. One end of sling was shackled to the panel's padeye (using a 25 MT bow shackle); the other end of the sling was connected to the crane's main hook via a large 250 MT shackle and two auxiliary wire rope sling legs (each 3.5″ diameter). This configuration is shown in Figure 1. The two 3.5″ sling legs formed a double-line connection from the crane hook to the junction with sling, providing additional reach and load capacity. All lifting gear had been inspected and load-tested in the months prior to the trial. Table 1 summarizes the key equipment and sling specifications for the lift.

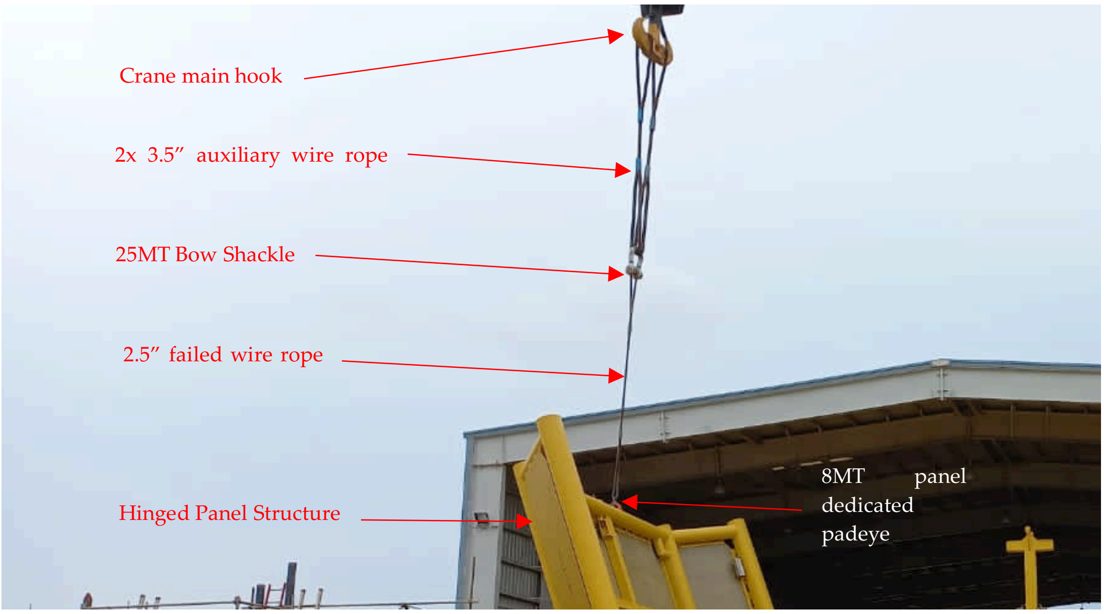


Figure 1. Initial rigging arrangement for the protection panel lift. The crane's hook (out of frame above) is connected via two 3.5″ wire rope sling legs and a large bow shackle to the single 2.5″ sling attached to the panel's lifting padeye. This setup was intended to pull the panel from horizontal toward vertical during the trial lift.

Table 1. Equipment and Sling Specifications (as used during the trial lift):

Item	Description / Specification
Crawler Crane	**350 MT SWL lattice-boom crane (mobile crawler), positioned ~40 m from panel hinge; main hook used for lift.**
Protection Panel	**~19.3 MT steel panel, hinged on subsea foundation; designed to require ~8 MT force via padeye to close. Padeye WLL 8 MT (single lifting point on panel).**

Item	Description / Specification
Primary Sling	**Wire rope sling, 2.5″ diameter × 15′ length. Rated SWL ~60 MT (≈54 tonnes) with minimum breaking load (MBL) 275 MT. Manufactured 2005 (17 years in service); last load test Jan 2022 to 69.1 MT.**
Auxiliary Slings	**2 × Wire rope slings, each 3.5″ × 20′. SWL 102 MT each. Used in double-line fashion between crane hook and primary sling. Manufactured 2009; last tested Jan 2022.**
Shackles	**250 MT bow shackle connecting auxiliary slings to crane hook; 25 MT bow shackle initially used at panel padeye (later replaced with 55 MT shackle for subsequent trials).**
Crane Instrumentation	**Load indicator in crane's cab (load cell system) and radius/angle sensors. Crane certification up to date (last inspection Sep 2021).**

3.2 Sequence of Events

Initial Lift Attempt: On the afternoon of April 7, 2022, the team proceeded with the first trial lift of the panel. The rigging was set as described, and the crane slowly took the slack and began lifting the free end of the panel off its supports. The panel was hoisted upward toward a vertical position while the crane boom was held relatively fixed. Almost immediately, the crane's load indicator showed a rapidly increasing load as the panel's weight shifted. The plan was to then slew the crane (swing the boom) to swing the panel shut. However, before the panel could fully close, the measured load exceeded the pre-set stop threshold. The crane operator announced a load of about 22 MT at a 42 m radius, surpassing the 20 MT limit given by the engineers, and the lift was halted. At this point the panel had been lifted into a near-vertical position but not closed. The first attempt was aborted due to the higher-than-expected force required – nearly three times the padeye's WLL – indicating that the panel was binding or resisting movement more than anticipated. The panel was carefully lowered back to its resting position without further incident.

Second Lift Attempt (Reposition and Travel Method): The engineering team paused to reconsider the approach. It was recognized that swinging the boom created a side-loading scenario on the sling and panel. For the second attempt, the crane was repositioned to face the panel more directly. The crane was moved (on its tracks) to be roughly in line with the panel's plane, so that the subsequent closing motion could be performed by tracking the crane forward (driving the crane) rather than swinging the boom. This aimed to pull the panel straight in, reducing side loads. The same sling was still used at this point, but the padeye shackle was upgraded to a 55 MT capacity shackle for a greater safety margin. Around 1:55 PM, the second trial commenced: the crane again lifted the panel up to vertical and then slowly travelled forward, attempting to push the panel from vertical toward the closed position. Despite the new approach, the panel refused to fully rotate into place – friction at the hinges or misalignment was preventing closure. The forces in the sling again built up beyond safe limits, and the team aborted the second attempt as well. The panel remained held by the crane, partially open, but it was clear another strategy was needed. The load experienced in this attempt was significant (later data indicated the force was on the order of tens of tonnes), though the exact value was uncertain due to instrumentation issues described later. After lowering the panel back down again, the team convened to plan adjustments.

Third Lift Attempt (Final, Failure): For the third and final attempt, the rigging was further modified. Recognizing that the required force was much higher than expected, the crew replaced sling with a higher-capacity sling (2.5″ diameter, same sling was actually of that size – the report clarifies this sling's specs as 2.5″, 60 MT SWL) and ensured all shackles were adequately rated (55 MT at the padeye, 250 MT at the hook). The crane was also positioned as close as feasible to the structure to minimize the reach and angle. Shortly after 3:15 PM, the third trial began: the panel was lifted once more toward vertical, and the crane slowly tracked to push it toward the closed position. This time the panel moved slightly further, coming very near to aligning in the closed position. Without warning, the primary sling suddenly parted. The failure occurred when the panel was almost upright, under peak tension. The severed sling recoiled and the panel, now free, swung back down under gravity, slamming into its original open position on the supports. Figure 2 shows how the moments before and after sling failure.

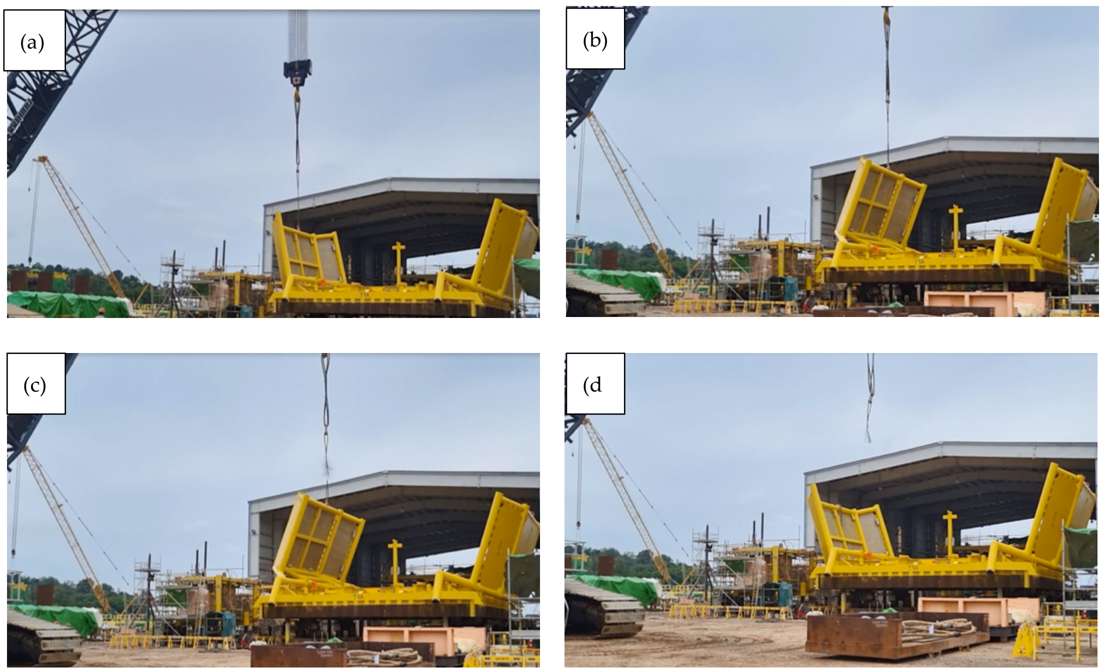


Figure 2. (a) Crane Rigging Attached To Panel At Open Position At Start Of SIT Trial Lifts. (b) Panel and Sling Inclination Prior to Parted. (c) Panel Position When Sling Parted. (d) Aftermath of the sling failure. The protection panel (right) is shown fallen back to its open position after the sling snapped.

Figure 3 shows how one frayed end of wire rope sling remains attached to the panel's padeye, and Figure 4 shows the other end recoiled toward the crane hook. Fortunately, all personnel were well outside the exclusion zone, and there were no injuries when the sling snapped and the 19-ton panel dropped. The two broken pieces of sling remained attached at each end — one piece still on the crane's hook and the other still secured to the panel's padeye. The crew immediately stopped all operations and secured the area. Within minutes, they lowered the crane hook to the ground, detached the remaining sling piece, and used a man-lift to recover the sling piece that was still on the panel. The incident was formally reported, and an investigation team was mobilized to examine the failure. The chronological of event is explained in Table 2 in timeline order.

Table 2. Event Timeline of the Incident: (Chronology on April 7, 2022)

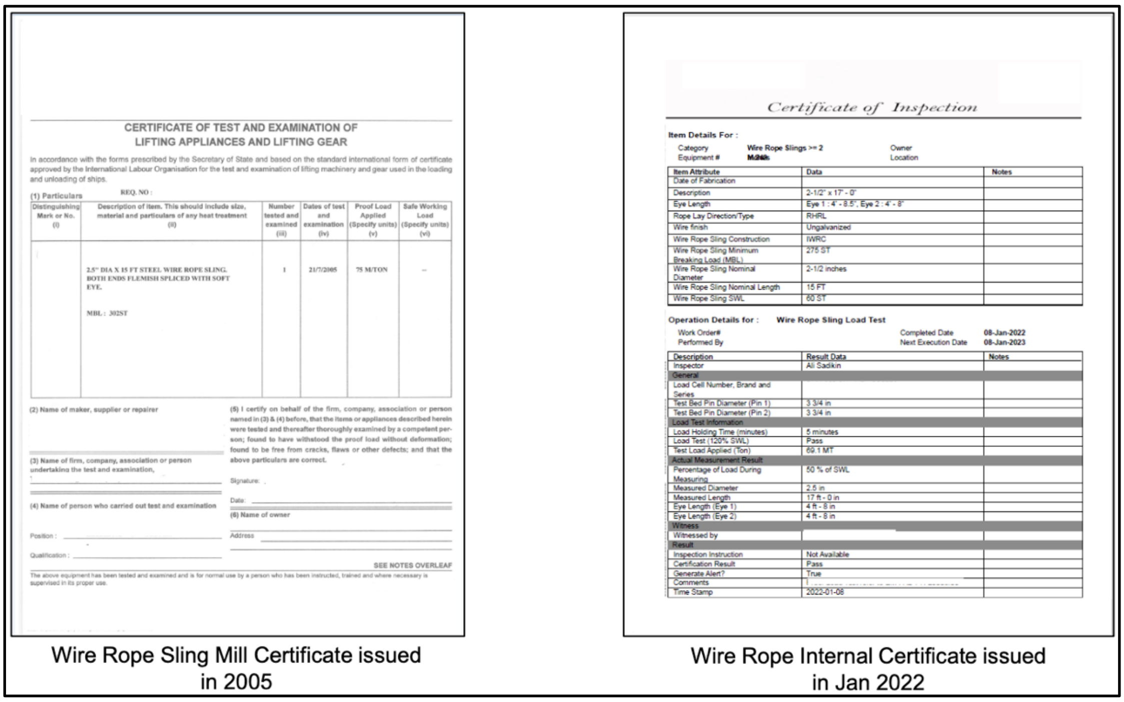
Time	Event
06:30 AM	Pre-lift preparations: SIT engineer briefs rigging team on trial lift plan. Rigging crew (foreman as lifting supervisor, with three riggers) gathers equipment and sets up crane at test location. Toolbox Talk (TBT) conducted; "Stop lift if load >20 MT" instruction given. Safety checks and permits completed (HIT card filed).
~1:30 PM	First Trial: Crane attached to panel; panel lifted from horizontal toward vertical. Load quickly exceeds expected value (≈22 MT recorded). Lift aborted before fully closing panel. Panel lowered back safely. Team notes that required force is much higher than design 8 MT – indicating unexpected resistance.
~1:55 PM	Second Trial: Crane repositioned parallel to panel; attempt to close panel by tracking crane forward. Panel again lifted and pulled toward closed position. Panel still will not fully close; high force observed (lift aborted again). Decision made to use a larger sling and bring crane closer.
3:15 PM	Third Trial: Rigging upgraded (higher-capacity sling, larger shackle); crane moved closer. Panel lifted nearly closed using crane movement. Sling fails catastrophically at peak load. Panel drops back open. All work stopped immediately.
3:20 PM	Post-incident actions: Area barricaded and secured. Broken sling pieces retrieved. Incident reported to management. Investigation initiated the same day.

Figure 3. The wire rope sling parted near its end termination – one frayed end remains attached to the panel's padeye (yellow circled).

Figure 4. The other end recoiled toward the crane hook. The failure occurred at the sling's ferrule (socket) where the wire rope is swaged, later found to contain corroded wires.

3.3 Investigation Findings and Observations

A detailed examination of the failed sling and a review of the operations was conducted by the contractor's investigation team. The wire rope sling was found to have failed at the ferrule (the metal sleeve securing the eye at the sling's end). Close inspection revealed that the wire strands inside the ferrule were severely corroded. The break appeared to originate where the rope enters the ferrule, suggesting a classic hidden corrosion fatigue failure, which significantly reduced the sling's strength. The sling had been in service for 17 years; despite passing a load test three months prior (*see Figure 5*), it was likely had diminished load capacity due to internal deterioration that went undetected in routine visual inspections.



CERTIFICATE OF TEST AND EXAMINATION OF LIFTING APPLIANCES AND LIFTING GEAR

In accordance with the forms prescribed by the Secretary of State and based on the standard international form of certificate approved by the International Labour Organisation for the test and examination of lifting machinery and gear used in the loading and unloading of ships.

(1) Particulars REQ. NO :

Distinguishing Mark or No. (i)	Description of item. This should include size, material and particulars of any heat treatment (ii)	Number tested and examined (iii)	Dates of test and examination (iv)	Proof Load Applied (Specify units) (v)	Safe Working Load (Specify units) (vi)
	2.5" DIA X 15 FT STEEL WIRE ROPE SLING. BOTH ENDS FLEMISH SPLICED WITH SOFT EYE. MBL : 302ST	1	21/7/2005	75 M/TON	–

(2) Name of maker, supplier or repairer

(3) Name of firm, company, association or person undertaking the test and examination,

(4) Name of person who carried out test and examination

Position :

Qualification :

(5) I certify on behalf of the firm, company, association or person named in (3) & (4) before, that the items or appliances described herein were tested and thereafter thoroughly examined by a competent person; found to have withstood the proof load without deformation; found to be free from cracks, flaws or other defects; and that the above particulars are correct.

Signature:

Date:

(6) Name of owner

Address

SEE NOTES OVERLEAF

The above equipment has been tested and examined and is for normal use by a person who has been instructed, trained and where necessary is supervised in its proper use.

Certificate of Inspection

Item Details For :

Category Wire Rope Slings >= 2 Owner

Equipment # [illegible] Location

Item Attribute	Data	Notes
Date of Fabrication		
Description	2-1/2" x 17' - 0"	
Eye Length	Eye 1 : 4' - 8.5", Eye 2 : 4' - 8"	
Rope Lay Direction/Type	RHRL	
Wire finish	Ungalvanized	
Wire Rope Sling Construction	IWRC	
Wire Rope Sling Minimum Breaking Load (MBL)	275 ST	
Wire Rope Sling Nominal Diameter	2-1/2 inches	
Wire Rope Sling Nominal Length	15 FT	
Wire Rope Sling SWL	60 ST	

Operation Details for : Wire Rope Sling Load Test

Work Order# Completed Date 08-Jan-2022

Performed By Next Execution Date 08-Jan-2023

Description	Result Data	Notes
Inspector	Ali Sadikin	
General		
Load Cell Number, Brand and Series		
Test Bed Pin Diameter (Pin 1)	3 3/4 in	
Test Bed Pin Diameter (Pin 2)	3 3/4 in	
Load Test Information		
Load Holding Time (minutes)	5 minutes	
Load Test (120% SWL)	Pass	
Test Load Applied (Ton)	69.1 MT	
Actual Measurement Result		
Percentage of Load During Measuring	50 % of SWL	
Measured Diameter	2.5 in	
Measured Length	17 ft - 0 in	
Eye Length (Eye 1)	4 ft - 8 in	
Eye Length (Eye 2)	4 ft - 8 in	
Witness		
Witnessed by		
Result		
Inspection Instruction	Not Available	
Certification Result	Pass	
Generate Alert?	True	
Comments		
Time Stamp	2022-01-08	

Figure 5. The sling had been in service for 17 years; despite passing a load test three months prior.

Apart from the metallurgical analysis of the sling, the investigation uncovered several contributing factors related to the planning and execution of the lift:

- Load greatly exceeded expectations: The force required to close the panel was far higher than the design intent (peak load estimated around 60 MT versus the 8 MT design load for the padeye). This was attributed to the method of lifting – using a single crane at one end of the panel introduced significant binding and side load on the panel's hinges, meaning the crane was effectively lifting much of the panel's weight and overcoming friction, rather than the panel swinging freely. The panel's weight estimation (≈19 MT) was accurate, but the method of applying force was not as envisioned in design, leading to a gross overload of the padeye and sling. Notably, a prior factory test had determined that using one crane on the padeye was not effective to close the panel – in that test, two cranes had been used to successfully close it – however, this lesson learned was not fully implemented in the planning of the SIT trial.
- Inadequate risk assessment and lift planning: The contractor's procedures classified this trial lift as a critical lift (due to the unusual rigging and high consequence of failure), which

would require a detailed risk assessment and specialized lift plan. However, the team on site treated it as a routine lift. No formal task risk assessment was conducted beyond the standard pre-job briefing. The decision to proceed with a single-sling, single-crane method, despite the known difficulties, represented a deviation from recommended practice without a proper management-of-change. The lack of a Critical Lift Plan and oversight meant that hazards like the padeye overload and sling stresses were not fully evaluated.

- Use of an aged sling without detecting internal damage: The failed sling had been maintained in the rigging inventory for many years. While it had proper certification documents and recent load test records, there was no age-based retirement criterion for slings in use – meaning an older sling could remain in service if it passed visual inspections and load tests. The investigation noted that the sling's storage conditions (often outdoors in a marine yard environment – *see Figure 6*) likely contributed to internal corrosion. The internal corrosion was not outwardly visible and was missed during inspections. This latent defect left the sling weaker than its rated capacity. When the sling experienced the high tension during the third trial, it failed below its original MBL, at the corroded section.

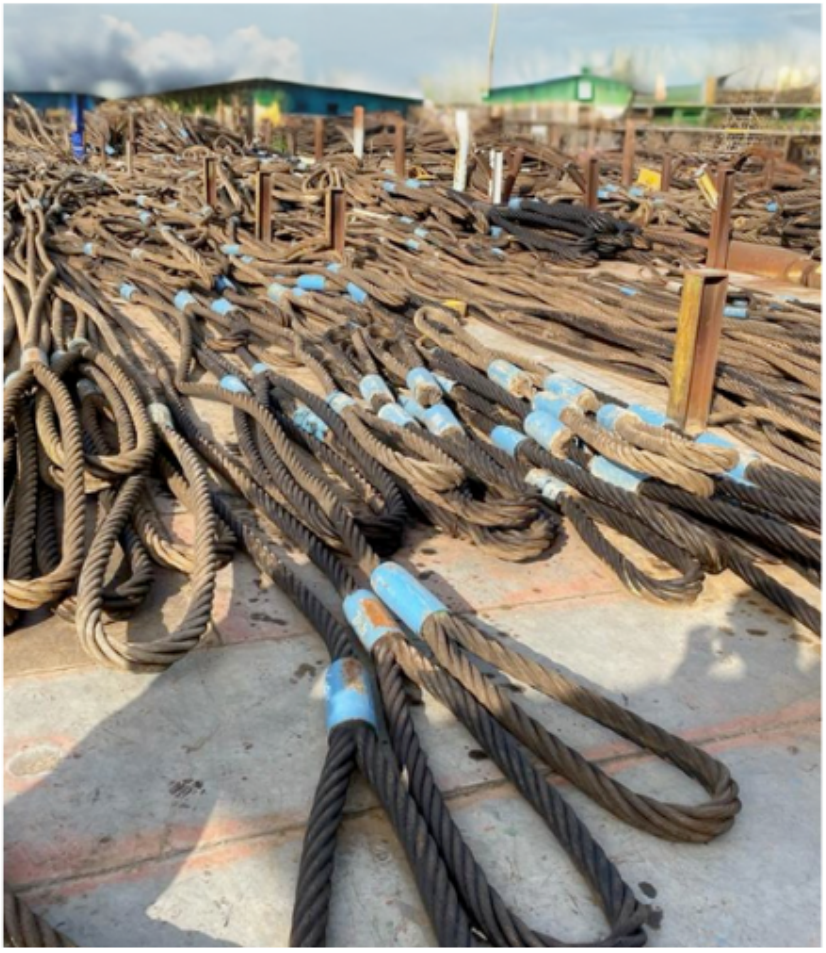


Figure 6. Sling outdoor storage condition

- Operational signals and Stop-Work: During the operations, the lifting team did register that the load was exceeding safe limits (as evidenced by the first abort at 22 MT). However, after re-rigging, when similar or higher loads were encountered, no one exercised Stop-

Work Authority to halt the job for a re-evaluation of the overall approach (beyond just upgrading the sling). The investigation highlighted that once the padeye's 8 MT limit was exceeded by a large margin, the operation should have been re-assessed from first principles. There was an over-reliance on simply using a bigger sling and crane, rather than addressing the fundamental issue of the method. Fortunately, the safety exclusion zone was maintained, which prevented any injuries when the sling ultimately failed.

Table 3. Key Findings from the Contractor's Investigation:

Key Finding	Details
Sling failure due to hidden corrosion	The wire rope sling failed at its ferrule, where internal corrosion of the wires was found. This corrosion significantly weakened the sling, causing it to part under a load well below its original breaking strength.
Actual load far above design capacity	The force required to close the panel (~60 MT) vastly exceeded the panel padeye's rating (8 MT) and the sling's intended safe load. The single-crane method induced high friction and side loads, effectively resulting in a severe overload of the rigging.
Lift misclassified as standard	The operation was treated as a standard lift instead of a critical lift, contrary to procedure. A detailed lift plan and risk assessment were not carried out, and a planned two-crane method (from earlier testing experience) was not used.
Deficient risk mitigation	When warning signs appeared (load readings over limit, earlier attempts aborted), the team did not stop and comprehensively reassess the plan. The Stop-Work Authority was not utilized despite clear indications of danger (padeye and sling overload).
Aged equipment and lack of criteria	The failed sling had been in service for 17 years. No specific retirement age criteria existed, and periodic inspections did not reveal its internal deterioration. Storage conditions and infrequent specialized audits may have contributed to its degraded state.
Equipment issues (secondary)	The crane's load monitoring system was found to have a faulty sensor, causing unreliable data. Although not a direct cause of the failure, this issue complicated the real-time assessment of the load and underlined the importance of robust equipment checks.

- Crane instrumentation and load readings: Post-incident analysis of the crane's onboard computer logs showed some inconsistent data. In fact, the crane's boom angle sensor was later found to be faulty, which called into question the precision of some recorded load values (the sensor error can affect how the load moment is calculated). A calibration check after the incident revealed the load cell was giving fluctuating readings at certain angles. Regardless of this instrumentation issue, the evidence of the physical overload (bending of the sling, the eventual break, etc.) confirmed that the forces were far beyond normal limits. The faulty sensor contributed to some confusion (for instance, the crane indicated ~60.3 MT at failure, a value which may or may not have been accurate), but it did not cause the incident – rather, it meant the operators did not have a perfectly reliable indication of actual load. The true load was likely extremely high, consistent with the sling failure.

In summary, the case involved a convergence of factors: an underestimation of the forces required, use of an inadequately inspected sling, and shortcomings in lift planning and hazard recognition. The contractor's investigation concluded that the sling parted primarily due to mechanical overload aggravated by internal corrosion. The incident underscores the need for rigorous critical lift planning, consideration of alternate methods (such as using multiple lift points or cranes for heavy hinged structures), proactive retirement of aging slings, and attentive execution with the willingness to halt work when conditions deviate from expectations. The findings from this case were to be used to improve lifting practices and prevent similar occurrences in the future.

Chapter 4: Critical Analysis

4.1 Application of RCA and Bowtie Methodology

The root cause analysis (RCA) methodology as explained in Chapter 2 is applied to evaluate the contractor's investigation of the wire rope sling failure. A cause-and-effect analysis was conducted, integrated with a Bowtie approach to map out both the contributing causes (threats) and the consequences of the sling failure event. Figure 6 illustrates a simplified Bowtie diagram for the sling failure, highlighting key causal factors on the left and potential outcomes on the right. This diagram places the *wire rope sling failure* as the central "top event," fed by multiple hypothesized causes such as *excessive load*, *wear/corrosion*, *improper rigging angle*, and *manufacturing/material defects*. These factors align with common failure causes identified in literature – for instance, excessive wear, corrosion, and overloading are frequently cited precursors to wire rope breakage [2]. On the right side, Figure 7 shows the likely consequences of a sling break (e.g. dropped load, equipment damage, injury), which underscore the high risk nature of such failures. The Bowtie also conceptually includes barrier controls: for example, *regular inspections* to catch corrosion or *adherence to load limits* to prevent overload. This integration of Bowtie analysis ensures that the evaluation not only considers why the sling failed (causes) but also whether adequate preventive barriers were in place or missing. By applying this methodology, we can systematically examine whether the contractor's investigation identified the same spectrum of causes and assessed the effectiveness of existing controls.

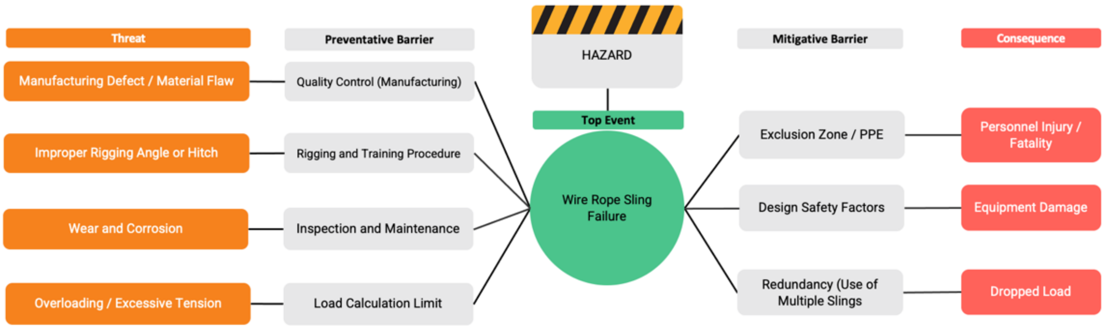


Figure 7. Simplified Bowtie diagram for the wire rope sling failure, showing key contributing causes (left side) and consequences (right side), along with examples of preventive and mitigative barriers (grey).

Using this RCA/Bowtie framework, the contractor's findings can be critically analyzed for completeness and depth. The Bowtie diagram helps visualize how each cause was addressed in the investigation. For instance, one hypothesized cause was wear and corrosion of the sling. Localized wear and plastic deformation can initiate stress concentrations leading to fatigue fracture in wire ropes [2]. The contractor through their presentation, did note corrosion near the sling's ferrule (end termination), suggesting they recognized a degradation mechanism. However, a rigorous RCA would probe further: *Was corrosion the primary contributor to failure, or did it simply exacerbate an overload condition?* Similarly, improper rigging or side loading (bending the sling at an angle) appears in the Bowtie as a potential cause. Side loading is known to dramatically increase stress on a sling and reduce its effective strength [11], yet the contractor's analysis should confirm if such off-axis loading occurred during the lift. In the incident, evidence shows the crane movement caused a side pull on the sling, increasing the tension beyond straight-line conditions. An effective RCA connects this operational factor to the failure: e.g. by noting that the sling experienced a higher load due to geometry, consistent with modelling studies on bending effects. Another threat in Figure 6 is *excessive load* relative to the sling's safe working limit. The contractor's data (crane log indications and the weight of the panel being lifted) strongly suggest that the sling was overloaded – possibly far beyond the pad eye's 8 MT design load – which would directly cause failure if true. Bowtie analysis encourages verifying whether safeguards against overload were present (such as load calculations or real-time load monitoring) and if they failed. In this case, the crane's load cell readings were unreliable due to a sensor fault, meaning a key preventive barrier (accurate load feedback) was compromised. Overall, the methodology helps ensure each causal pathway is considered and that the contractor's investigation is measured against a comprehensive map of potential causes and missed barriers.

4.2 Assessment of the Contractor's Investigation in Relation to Established Best Practices

Having mapped out expected causes and controls, we now evaluate the contractor's investigation using criteria derived from peer-reviewed case studies on wire rope failures. Table 4 summarizes this evaluation, comparing the investigation's scope and findings against industry best practices [2][7][10]. Key areas of evaluation include the completeness of failure analysis, correct identification of failure mode and root cause, and the procedural rigor of the investigative approach.

- Failure Mode Identification: The contractor's report indicates the sling "parted at the ferrule with signs of wire corrosion." This suggests a failure mode potentially involving corrosion-assisted breakage, but it remains unclear if the break was due to gradual fatigue or an instantaneous overload. Peer-reviewed investigations stress the importance of determining the failure mode via fractographic and metallurgical analysis [14][7]. For example, fatigue fractures initiated by decarburized micro-cracks in a failed crane rope, using microscopic examination [7]. In the contractor's case, no mention of detailed fracture surface examination or wire break morphology was made; thus, the precise failure mode was left somewhat ambiguous (the report lists "undetermined corrosion" as a factor). This is a partial gap – while the presence of corrosion was noted (a clue toward possible fatigue or stress corrosion cracking), a conclusive determination (e.g. overload versus fatigue failure) was not documented. Without techniques like scanning electron microscopy [2], the investigation may have missed distinguishing whether corrosion caused a brittle stress-corrosion failure at the ferrule or simply weakened the sling which then snapped in overload.
- Root Cause Identification: The contractor did identify numerous contributing factors, extending beyond the broken sling itself. Notably, they recognized latent organizational issues – for instance, the lack of a defined retirement age for slings (the failed sling was ~17 years old with no replacement criteria) and shortcomings in risk assessment (treating a complex lift as a routine operation). These align with best practices in RCA, which call for probing into not just *what* failed, but *why* the conditions for failure were present. The investigation enumerated causes ranging from procedural errors (inadequate hazard assessment, bypassing of management-of-change processes) to environmental factors (outdoor storage leading to corrosion) and human factors (decision to proceed with one-crane method despite a previous two-crane failure). This breadth shows commendable scope and mirrors the multi-factor approach seen in case studies. For example, a manufacturing lapse (mixing of wire grades) as the root cause of a rope's premature failure [10]. Similarly, the contractor's analysis did not stop at the broken sling's condition; it dug into *why* an old, possibly degraded sling was still in use, and *why* the operation overstressed it. In terms of root cause identification, the investigation meets the standard by uncovering systemic issues (e.g. lack of critical lift planning, inadequate maintenance policies) that set the stage for the sling's failure. One area for improvement is clearer prioritization of these causes – the report listed seven "COMET factors" but did not explicitly label any single factor as *the* root cause. A more explicit linking of the chain (for instance: improper risk assessment led to use of one crane and an old sling, which led to overload and failure) would improve clarity.
- Analytical Rigor and Evidence: A strong failure investigation relies on thorough evidence collection (visual inspection, nondestructive examination, laboratory testing) [14]. The contractor's team performed a visual examination (noting corrosion at the ferrule) and reviewed load test records and crane logs. However, there is no indication of metallurgical analysis of the failed sling segment (such as sectioning the ferrule to inspect internal

corrosion, or microscopic examination of broken wire ends). By contrast, published case analyses usually include such examinations – for example, stereoscopic fractography and microhardness tests were used to correlate failure features with operational conditions [2]. Without similar tests, the contractor's conclusion about corrosion remains qualitative. The investigation could be considered incomplete in forensic analysis: it did not quantify the extent of internal corrosion or confirm if the mode of failure was ductile overload or fatigue. This is a notable miss, because a laboratory analysis might have revealed, say, a fatigue beach mark pattern or a brittle fracture surface, altering the emphasis of the root cause. On a positive note, the investigation did incorporate operational data (crane computer logs, test history), which is in line with comprehensive analysis – it recognized that the *operational context* (load magnitude, side-loading due to crane movement, etc.) was critical to the failure. In summary, the evidence gathering was sufficient to identify obvious factors but fell short of the depth seen in peer-reviewed failure analyses.

- Procedural Rigor: The methodology followed by the contractor shows elements of a formal RCA. The use of a timeline of events, a list of contributing factors (labelled as latent issues and direct causes), and a set of corrective actions indicates a structured approach. This mirrors standard investigative processes and even the Bowtie paradigm, wherein hazards (e.g. an 8 MT pad eye being used in a high-load scenario) are linked to threats (causes) and controls (or lack thereof). The investigation could have benefitted from explicitly using an RCA tool (such as a fault tree or fishbone diagram) to visualize cause-effect linkages for clarity, but the content implies these linkages in narrative form. Importantly, the investigation considered human and organizational factors – a hallmark of rigorous analysis. For instance, it identified that the team knowingly exceeded the pad eye's limit without a proper MOC (Management of Change) approval, and that lessons learned from a factory test (FAT) were not implemented. By acknowledging these, the contractor's team demonstrated a systems-thinking approach consistent with modern accident analysis models. One minor critique is the lack of external peer review or reference to standards in the report – the analysis was internal, and there is no mention of consulting wire rope failure standards or guidelines (for example, ISO or ASTM standards for sling inspection, or published criteria for retirement). Incorporating such benchmarks (e.g. citing that no internal wire breaks were acceptable per ISO standards, or that 17 years far exceeds typical sling service life in marine environments) would strengthen the authority of the conclusions. Nonetheless, the overall procedural rigor was strong, addressing multiple facets and producing actionable recommendations.

Table 4. Summary on how the contractor's investigation compares to key criteria drawn from the literature.

Evaluation Criterion	Assessment of Contractor's Investigation
Failure Analysis Completeness	*Partial.* Visual examination and operational data were assessed, but limited forensic analysis of the failed sling was performed. No metallurgical tests or detailed fractography were reported, whereas case studies recommend such analysis for conclusive results [2].
Failure Mode Identification	*Partial.* Corrosion at the failure point was observed, but it was uncertain if failure was by overload or fatigue. The investigation lacked definitive evidence (e.g. microscope fractography) to classify the failure mode, unlike peer analyses that clearly distinguish fatigue vs. overload [7].
Root Cause Depth	*High.* The investigation went beyond the immediate cause to identify multiple underlying causes (procedural failures, lack of maintenance policies, environmental factors). This systems approach meets best-practice standards, as seen in comprehensive case reviews [10].
Procedural Rigor in Analysis	*High.* A structured RCA-like process was evident (timeline of events, cause factor list, actions). Human, technical, and organizational factors were all considered. The thoroughness in identifying latent issues (e.g. training and audit deficiencies) reflects a robust methodology.
Adherence to Best-Practice Criteria	*Moderate.* The investigation addressed major factors and provided recommendations, but it did not reference external standards or criteria for wire rope condition (e.g. discard criteria, design factors). It also lacked independent expert review. Aligning findings with industry standards (for instance, criteria for retirement due to age/corrosion) would further validate the conclusions.

In summary, the contractor's investigation was broad in scope and identified key contributors to the sling failure, matching well with the multifaceted causes reported in literature for similar cases. The inclusion of factors like inadequate risk assessment and sling age/corrosion shows an understanding that accidents arise from multiple failings, not just a single point of hardware failure. This aligns with peer-reviewed case studies where investigators found combined causes (e.g. material defects plus operational overload) behind wire rope failures [7][2]. The main shortcomings of the investigation lie in the depth of technical failure analysis – specifically, the lack of detailed metallurgical examination – and in fully documenting adherence to criteria (no explicit citation of standards, and uncertainty in failure mode determination). These gaps could be filled by a more rigorous application of the RCA methodology: for example, performing a laboratory failure analysis to conclusively determine how the sling broke, and using a Bowtie diagram or fault tree to ensure all possible causes and missed barriers are accounted for and communicated clearly. Overall, however, the investigation's findings are consistent with known failure modes of wire rope slings and provide a solid basis for the preventive actions recommended.

Chapter 5: Discussion

5.1 Alignment with Best Practices and Literature on Sling Failures

The contractor's investigation findings largely align with known failure mechanisms for wire rope slings, while also revealing some gaps compared to best practices. The analysis determined that the sling failure was precipitated by in-service deterioration – specifically internal corrosion at the ferrule and accumulated wear due to long service and poor storage. This accords with the broader literature on wire rope failures, which emphasizes that progressive damage like wear, corrosion, and localized deformation can create stress concentrations leading to fatigue fractures [2]. Even under normal operations, small-scale wear and plastic deformation in ropes will amplify local stresses and eventually trigger sudden fatigue failure [2]. The failed sling in this case, having been in service since 2005, exhibited exactly such hidden degradation (corrosion in the termination) that was not apparent in routine inspections or a recent load test. This finding is consistent with failure analysis of a crane rope, where undetected defects combined with cyclic loading led to fatigue cracking; they concluded that fatigue, exacerbated by inadequate inspection, was a primary cause of rope rupture [7]. In this incident, the fact that the sling passed a load test only weeks before failure yet still broke underscores the challenge of detecting internal flaws – subtle defects (like decarburization cracks in steel wires) can escape notice and initiate failure [7]. The contractor's identification of internal corrosion as a root cause shows an awareness of these failure modes and reflects an alignment with best practices in failure investigation, which call for looking beyond obvious external damage.

Notably, the investigation did not find evidence of manufacturing or design defects in the sling, focusing instead on deterioration and operational factors. This is an important distinction from some cases in the literature where the root cause traced back to material or manufacturing issues. For instance, a wire rope failure that was ultimately caused by a manufacturing error: the rope was built with a mix of low- and high-strength wires, contrary to specifications, leading to uneven stress distribution and premature wire breaks [10]. In the present case, the sling had been certified to the correct capacity and had a long service history, suggesting no such intrinsic defect. The failure therefore diverges from such scenario, and instead aligns more with wear-and-tear induced failures [2], emphasizing the role of service conditions rather than manufacturing quality. That said, the contractor's plan to send the broken sling for third-party laboratory analysis indicates a commendable thoroughness. Engaging in metallurgical failure analysis (as done in published studies [2]) could confirm the micro-mechanisms of failure and ensure no contributing factor (such as an undetected material anomaly) is overlooked. This step goes beyond many routine investigations and shows an effort to meet the rigor seen in scholarly analysis of sling failures.

Overall, the technical conclusions of the contractor's investigation are well-grounded in established knowledge. The determination that *inadequate maintenance and inspection regimes* allowed a deteriorated sling to remain in use is strongly supported by prior studies. As one best-practice guideline notes, wire ropes must be removed from service before damage (wear, corrosion, broken wires) accumulates to a critical level [7]. In this incident, the absence of an age-based retirement criterion for slings – the sling was 17 years old – was a clear lapse. The investigation acknowledged this by pointing out the lack of a procedure for age-based rejection and recommending that slings older than 10 years be retired. This corrective action resonates with the preventative focus advocated in literature: discard criteria should consider not only visible damage but also time-related degradation [7]. In sum, the investigation's findings (internal corrosion, side-loading during the lift, insufficient pre-job planning, etc.) align with known causes of sling failure, and the areas where it diverged from ideal practice (e.g. the need for more proactive inspection standards) were recognized and addressed through recommended actions.

5.2 Implications for Investigation Quality and Organizational Learning

Beyond the technical cause, this case carries broader implications for improving incident investigations and fostering organizational learning in lifting operations. One positive aspect is the investigation's comprehensive approach in identifying not just the immediate cause of the sling failure, but also underlying organizational and process weaknesses. The analysis went on to examine why the situation arose – uncovering issues like improper lift planning, failure to heed prior test lessons, and gaps in safety procedures (such as the lack of a defined "critical lift" protocol and lapse in applying Management of Change when the plan deviated). By tracing contributing factors through management and communication lapses, the inquiry reflects a systems-thinking approach that is often championed in safety literature. This is in contrast to more superficial investigations that focus only on operator error or hardware failure. Indeed, recent research on incident investigations has warned that focusing solely on "sharp-end" factors (frontline mistakes or isolated technical faults) tends to yield weak corrective actions that don't prevent recurrences [13]. In this incident, the contractor's team avoided that pitfall: they looked at latent organizational conditions – such as procedure deficiencies and cultural aspects (e.g. reluctance to exercise Stop-Work Authority) – and issued recommendations to address these deeper issues. This aligns with best-practice models of learning from incidents, which stress that true improvement comes from addressing systemic weaknesses and not just replacing the broken part or blaming personnel [13].

However, the case also highlights challenges in translating lessons into practice, an area where organizational learning must be strengthened. It was noted that a similar lifting attempt during Factory Acceptance Testing (FAT) had failed, and lessons learned (LL) were circulated, yet the project team proceeded with essentially the same approach that led to the sling failure.

This lapse indicates a breakdown in cross-project learning and knowledge transfer. Research in accident prevention emphasizes that recurring incidents with the same root causes are a sign that organizations are not effectively learning from past mistakes [13]. Recurring accidents were attributed to companies addressing surface-level problems while deeper issues persisted, and often failing to implement or follow up on recommended remedial measures [13]. This case follows this pattern: despite prior warning from the FAT, the knowledge was not institutionalized into planning or procedures, resulting in a repeated failure. The key implication is that organizations involved in lifting operations need more robust mechanisms for capturing and applying lessons learned. Simply holding post-incident meetings or disseminating a memo is not enough; there must be a systematic integration of those lessons into revised standards, training, and decision-making for future lifts.

Improving the quality of investigations plays a pivotal role in this learning cycle. The thoroughness of this particular investigation – which produced a detailed cause analysis and a multifaceted action plan – sets a high benchmark. It demonstrates how a well-conducted investigation can directly feed into organizational improvement. For instance, the action plan from this inquiry included tangible changes: new engineering controls (e.g. requiring dual cranes or revised rigging methods for similar lifts), procedural updates (implementing a critical lift registry and stricter sling retirement criteria), enhanced training (counselling the team on stop-work authority and refreshing the Management of Change process), and even a *Just Culture* review to ensure accountability is balanced with learning. Such breadth of remedial actions is indicative of a learning-oriented investigation outcome, as it addresses technical fixes and process/cultural reforms. This approach is precisely what the literature advocates for high-hazard industries – learning from incidents should trigger both immediate fixes and deeper organizational changes to reduce risk long-term [13].

Going forward, lifting operations can benefit from the lessons of this case by institutionalizing higher investigation standards and learning practices. First, organizations should ensure that any significant near-miss or equipment failure (like a sling snap) is analysed with the same rigor as a high-consequence accident, potentially involving third-party experts when needed to get to root causes. Second, the feedback loop from investigation to action needs to be swift and effective: as this case shows, having a clear timeline and responsibility for each recommended action (ranging from technical audits to procedure revisions) is critical. Finally, there should be an emphasis on knowledge sharing – both within the organization and across the industry. The recurrence of a preventable failure mode is far less likely when companies treat every incident as a learning opportunity and proactively update their practices. By comparing investigation findings with established best practices (as we did here using peer-reviewed studies) and by committing to continual improvement, lifting operations can significantly enhance their safety performance. In essence, the contractor's investigation – with its mix of aligned findings and candid exposure of procedural gaps – serves as a catalyst for organizational learning. It reinforces that thorough incident investigations are not just post-mortems of failure, but a cornerstone of *prevention*, enabling evidence-based improvements in equipment maintenance, risk assessment, and safety culture for future operations.

6. Recommendations

Based on the investigation findings, the following concise recommendations are proposed, targeting both the contractor involved in the incident and the wider lifting operations community:

- Enhance Sling Inspection and Maintenance: Enforce a rigorous inspection program with daily pre-use checks by a competent person. Damaged slings, such as those with broken wires or corrosion, should be immediately removed from service. Following established discard criteria ensures worn slings are retired before failure.
- Proactive Replacement of Aged or Damaged Slings: Implement a policy to retire slings after a reasonable service life or harsh use, even if they pass inspections. Research shows that wire ropes can wear out quickly under heavy use, and past failures highlight the need for proactive removal. Maintain detailed sling records to guide timely replacements.
- Improve Lift Planning and Risk Assessment: Strengthen procedures for planning complex lifts, classifying high-risk operations as critical lifts. Incorporate lessons from prior tests and ensure operations stay within equipment limits, adjusting rigging strategies when necessary. Hazard analyses should specifically consider the planned lift manoeuvre.
- Use Proper Sling Configuration to Minimize Stress: Ensure slings are used in configurations that prevent excessive bending or improper loading. Verify that rigging hardware meets recommended diameter ratios and angle restrictions to avoid internal wear. By adhering to design parameters, contractors can reduce the risk of sling failure.
- Reinforce Standards Compliance Across Industry: Ensure strict adherence to wire rope sling standards and regulations by all stakeholders. Require evidence of compliance, such as inspection logs and sling certifications, to promote a safety culture. Emphasizing these standards helps maintain sling integrity and ensures safe usage across all projects. This approach reduces the risk of accidents caused by degraded slings.
- Disseminate Lessons and Training on Failure Mechanisms: Actively share lessons learned from failure case studies to enhance collective knowledge. Incorporate real-world examples, such as undetected fatigue cracks and corrosion, into training programs for rigging inspectors and engineers. This will help identify critical warning signs and prevent catastrophic sling failure. Industry conferences and safety publications should circulate this information to promote proactive safety measures.
- Continuous Improvement of Equipment and Practices: Encourage the development and use of advanced inspection techniques, like non-destructive testing (NDT), especially for slings in critical service. Update industry guidelines to address issues revealed by failure incidents, such as defining more conservative safe life limits for slings. Promote a strong safety management system, including hazard identification and "stop-work" authority, to halt operations if abnormal conditions arise. These improvements will reduce sling failures and enhance lifting safety.

7. Conclusion

The investigation into the wire rope sling failure revealed that both technical and organizational factors contributed to the incident. The immediate cause was the sling's rupture due to undetected internal corrosion, which was exacerbated by overloading during a non-standard lift. Root Cause Analysis (RCA) identified two primary issues: the sling's severe internal corrosion, which routine inspections failed to detect, and procedural failures, including inadequate lift planning and a lack of safety oversight. These oversights highlighted gaps in risk management and communication.

The findings prompted corrective actions, including stricter sling inspection and retirement policies, better adherence to lift planning and load limits, and improved communication of lessons learned across the team. These measures are aimed at preventing similar failures and fostering a more proactive safety culture. Ultimately, the investigation served as a catalyst for improvement, with the application of RCA leading to enhanced practices and standards to improve the safety and reliability of future lifting operations.

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